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THESIS

CONSTRUCTION AND USE OF A
RADIO CONTROLLED MODEL HELICOPTER
FOR RESEARCH

by

Charles J. Hintze

March 1985

Thesis Advisor: Donald M. Layton

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Construction and Use of a Radio Controlled Model Helicopter for Research

by

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Submitted in partial fulfillment of the requirements for the degree of

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I. INTRODUCTION

A. GENERAL

The development of the vertical lift machine envisioned by Leonardo da Vinci in the 15th century has evolved into the present-day helicopter. During these past five centuries, the design and the development of the helicopter, as we know it today, is the combined result of many individual efforts. The theories and designs that these individuals developed could not have been substantiated without sound experimental evidence obtained from actual rotary wing aircraft flight tests.

Today, the design and development of the helicopter continues. The use of new methods and technology, especially computers will result in new theories and computer-generated designs. As in all theories and designs, these new ones can not be substantiated without sound experimental evidence. The rising cost of developing and testing an experimental helicopter has excluded almost everyone from conducting experiments except for the major helicopter corporations. A possible, relatively inexpensive solution for conducting testing at colleges and universities, may be in the use of a radio controlled model helicopter.

B. OBJECTIVES AND SCOPE

The objective of this thesis is to investigate the similarities and the differences between a radio controlled model helicopter and a full-size helicopter. If the radio helicopter is more similar to a full-size helicopter than different, construction of a radio controlled model helicopter and flight training will be accomplished. Initial hover performance testing will be attempted and evaluated.

II. APPROACH TO THE PROBLEM

Two radio controlled model helicopter books [Refs. 1,2] were selected for comparison with full-size helicopter performance books [Refs. 3,4] to determine the similarities and differences between a radio controlled model helicopter and a full-size helicopter.

It was decided that if a radio controlled model helicopter was quite similar to a full-size helicopter, a radio controlled model helicopter was to be constructed either from scratch or from a kit. Other decisions included whether a fuselage or an open design airframe would be used, type and size of the engine needed to power the model helicopter, and type of radio control to be used. Use of published material, in particular references 1 and 2, and advice from operators of remote controlled model helicopters assisted in making these determinations.

Once these determinations were made, the model was assembled and the operator had to learn how to fly the remote controlled model helicopter. Flying proficiency can only be obtained through repeated flights. Only after flying proficiency is accomplished can testing begin. A tethered hovering performance test will be used to investigate and evaluate the engine and airframe performance of the constructed radio controlled model helicopter. The tethered hovering performance test will be conducted at various altitudes and rotor RPM, with the data recorded and then reduced for evaluation.

III. RADIO CONTROLLED MODEL AND FULL-SIZE HELICOPTER COMPARISON

A. GENERAL

Since a great majority of radio controlled model helicopters are of a single main rotor and tail rotor design, only this type of helicopter will be analyzed for comparison with full-size helicopters. Some familiarity with the basic helicopter terminology is assumed.

When comparing the radio controlled model helicopter to a full-size helicopter, there are many similarities which are found between these two types of helicopters. Rather than discuss these numerous similarities, only the major differences between a radio controlled model helicopter and a full-size helicopter will be discussed. Excellent discussions on the basic technology of all helicopters in the areas of helicopter aerodynamics, performance, and stability and control can be found throughout references 1-4.

B. DIFFERENCES

1. Engines

Modern full-size helicopters usually contain a highly efficient gas turbine engine, and in some cases may contain more than one such engine. The engine contains a sophisticated fuel control for maintaining the required operating engine and rotor RPM.

The radio controlled model helicopter on the other hand is powered mainly by a single cylinder, two-stroke internal combustion engine. This type of power plant is very inefficient as only one third of each revolution actually produces power. Another third produces a braking effect due to compression. The final third of each revolution encompasses gas exchange, scavenging and transition between combustion and compression. [Ref. 1: p. 128]

2. Vertical Lift

There are two methods of controlling a helicopter in a vertical plane. One method is by altering the speed of rotation of the main rotor. The main rotor blades are fixed at a pre-determined angle of incidence which is designed to provide maximum thrust when the engine is running at its maximum RPM [Ref. 1: p. 130]. This method was used extensively in earlier model helicopters and is found today on some of the cheaper priced model helicopter kits.

The other method uses collective pitch control. In this method, the main rotor blades are not fixed but feature feathering hinges which allows the angle of incidence of the rotor blades to be varied in flight. Vertical movement is not controlled by altering the rotor velocity and, in fact, the rotor velocity remains constant. The angle of incidence of the the rotor blades is varied simultaneously or collectively, resulting in an immediate change in vertical control. [Ref. 1: p. 33] This method is employed on all full-size helicopters.

One reason the collective pitch control method is not normally used in radio controlled model helicopters is because of its requirement for a complex rotor head and control system. The balancing of the rotor blades and the controls and the adjustment of the push rods is also considered more difficult and complicated. However, the most important reason is that current model helicopter engines are unable to maintain the same rotor RPM under all conditions. [Ref. 1: p. 33]

For these reasons, most radio controlled model helicopters utilize a combination of collective pitch control and throttle control. This method attempts to open the throttle at a rate that will allow the rotor to maintain a constant RPM as the pitch is increased. In actuality, this is difficult to accomplish as any minor change in rotor setting, engine setting or even climatic environment can affect it.

3. Tail Rotor

Both types of helicopters counter act the torque produced mainly by the turning rotor through the use of a compensation device known as the tail rotor. However, in the model helicopter, it is not easy for a beginner pilot to learn how to utilize the tail rotor in controlling this torque. A gyroscopic stabilizer can be installed to help compensate or diminish this torque effect. The gyroscopic stabilizer sends a control signal to the tail rotor servo to counteract or lessen any change in heading of the fuselage. The gyroscopic stabilizer can be adjusted fairly accurately but it requires some experience as an incorrectly adjusted gyroscopic stabilizer can increase the torque problem. [Ref. 1: p. 37]

4. Controls

a. Full-Size Helicopter

The control arrangement of a full-size helicopter as shown in Figure 3.1 [Ref. 1: p. 43, Fig. 36], consists of:

The collective lever which is normally located on the pilots left side. It controls the vertical movement of the helicopter by varying the pitch of the main rotor blades. The collective usually features a twist grip

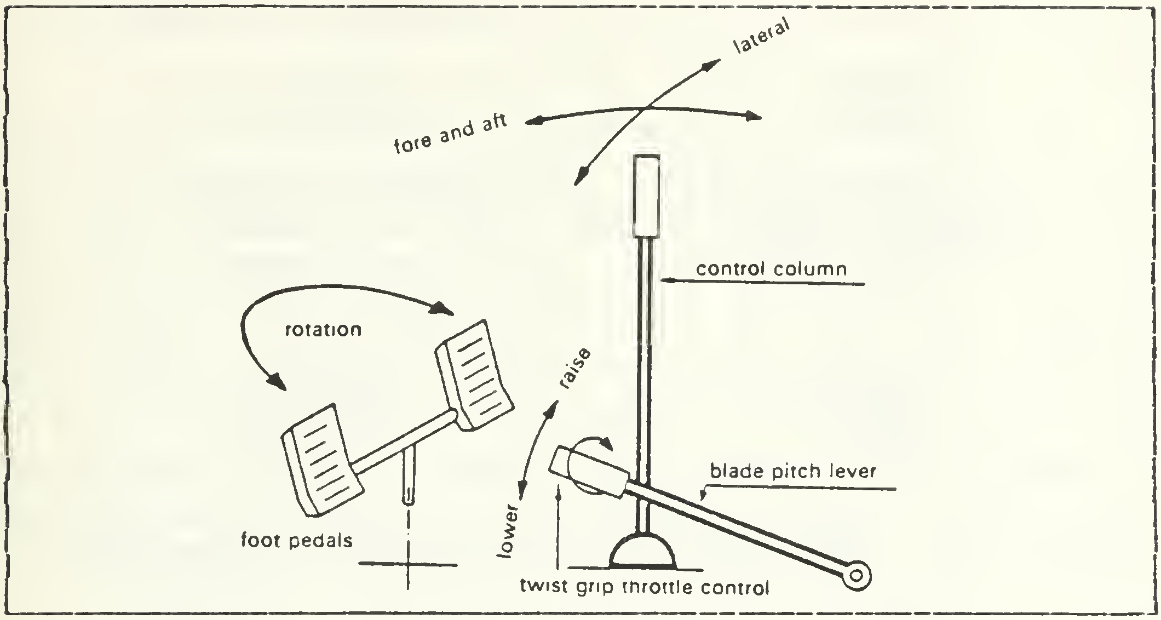

Figure 3.1 Full-size Helicopter Control Arrangement

throttle control. This is used to control the engine output if there is no automatic power control system.

Foot pedals are used to control the helicopter heading while at a hover. The pedals are also used to counter act the torque of the main rotor.

The cyclic control is located normally between the pilots legs. It is used to control the helicopters fore and aft movement and also its lateral movement.

b. Radio Controlled Model Helicopter

Radio controlled model helicopters are normally controlled by a total of four functions, two on each stick of the radio control as shown in Figure 3.2 [Ref. 1: p. 91, Fig. 77].

Vertical movement is accomplished by varying the engine throttle or the engine throttle/collective pitch control stick, which is the left hand stick on the radio control. Pushing the stick forward (away from the body)

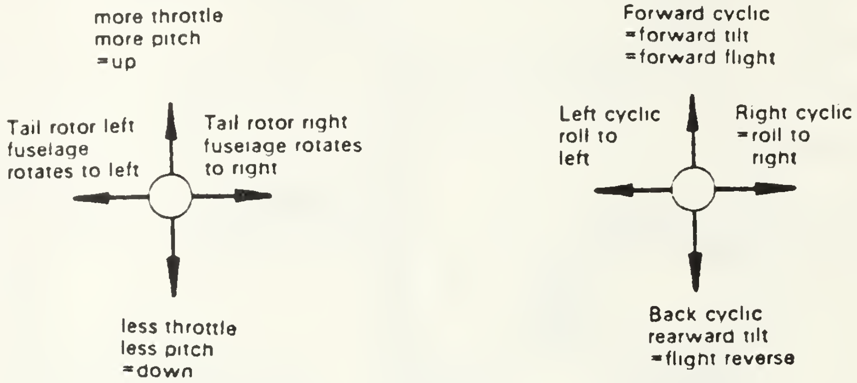

Figure 3.2 Model Helicopter Radio Control Arrangement

corresponds to a climb while pulling the stick back corresponds to a descent. The control stick is ratcheted to help maintain a desired altitude and/or throttle setting.

The helicopter heading is controlled by varying the tail rotor pitch and is best accomplished by the lateral movement of the left hand stick. Moving the stick to the left rotates the nose of the helicopter to the left and vice versa. The control should be laterally self-neutralizing to facilitate trimming for hovering flight. [Ref. 1: p. 45]

The fore and aft movement and the lateral movement are controlled by the right hand stick of the radio control. Pushing the stick forward corresponds to the helicopter moving forward, while moving the stick back corresponds to the helicopter moving to the rear. Moving the stick to the left causes the helicopter to slide or roll to the left and vice versa. This control should also be self-neutralizing both laterally and longitudinally to facilitate trimming for hovering flight. [Ref. 1: p. 45]

5. Main Rotor System

A helicopter is at best neutrally stable and more likely to be unstable. Full-size helicopters employ a number of rotor system designs, but they mainly use either the fully articulated, semi-rigid or the rigid rotor system. Modern full-size helicopters have been able to reduce instablity to an acceptable level such that the special stabilizing equipment of older helicopters is not required. Current radio controlled model helicopters tend to utilize a two bladed semi-rigid (teetering) rotor system because of its simplistic design, light weight and ease in rigging the controls [Ref. 2: p. 62].

If this teetering type of rotor system is low damped, it will be difficult to fly due to its short period diverging oscillations caused by rotor flapping. However, if the flapping of the rotor can be limited causing an increase in the period oscillation, the teetering rotor system becomes less unstable and easier to control. This can be accomplished by a number of methods, such as adding weight to the rotor tips, reducing the rotor RPM, installing rubber or spring dampers and/or by adding a stabilizing bar with or without weights or control paddles. [Ref. 2: pp. 48-55]

A majority of radio controlled model helicopters with the two bladed semi-rigid rotor system use a simplified Hiller or Hiller/Bell configuration for stability control. In the Hiller configuration, the rotor blades are operated indirectly by controlling the stabilizing paddles. This offers an advantage in that only small control forces are required, thus , maintaining a low servo load. A disadvantage of this configuration is that there is a time delay between control input and main rotor reaction. This delay can be minimized by making the paddles relatively large and light. [Ref. 1: pp. 60-61, 102]

In the Hiller/Bell configuration not only the control paddles, but also the rotor blades are directly operated. The time delays of the basic Hiller configuration are eliminated. No mechanical damping is required as it would be if only the Bell configuration was used. Weights can be added to the stabilizing bar which increases the stability of the helicopter while maintaining relatively rapid control reactions. [Ref. 1: pp. 103-104]

6. Instruments

In a full-size helicopter, there are flight, electrical and engine instruments which provide data to the pilot. There is usually additional room for installation of special instruments that may be required for a specific test or evaluation.

The radio control model helicopter has no instruments. It also has very little space in which any instruments could be installed. Since the radio controlled pilot is separate from the model helicopter, any instruments utilized should have some type of communications data link, possibly radio or wire, to furnish information from the helicopter to the pilot. The use of a wire link would limit the range and the operation of the model helicopter.

7. Rotor Rotation

On most American made full-size helicopters, the main rotor rotates counter-clockwise. The main rotor of most radio controlled model and full-size European helicopters rotate clockwise. When power is added to the counter-clockwise rotating rotor, the fuselage tends to rotate clockwise requiring a left tail rotor input for correction. The opposite is true for the clockwise rotating rotor. Some confusion can result during take-offs and landings as to what tail rotor correction is required if the radio control pilot is familiar with one system and is flying another.

IV. CONSTRUCTION OF A RADIO CONTROLLED MODEL HELICOPTER

A. CHOOSING A RADIO CONTROLLED MODEL HELICOPTER

There are two ways of constructing a radio controlled helicopter model. One, is to build the model from scratch. The other, is to build it using a prefabricated helicopter model kit. Since a scratch-built helicopter would require someone with experience in scratch-model building and would also require more time in construction, a decision was made to construct the radio controlled helicopter using a prefabricated model kit.

Two helicopter model kit designs , the fuselage and the open structure, were evaluated. In the fuselage design, the fuselage skin is the load-bearing element of the helicopter and is usually made of laminated glass-fiber reinforced polyester or epoxy resin. The mechanics of the helicopter must be fitted precisely and the fuselage must be constructed to fine limits. The open structure consists of a basic frame and no load-bearing fuselage. The frame can be made of plastic, a metal/plastic combination, or entirely of a light alloy. The basic frame is usually easier and faster to construct. It allows better accessibility for maintenance and repairs. Although the open structure design is more susceptible to contamination, it is also easier to clean. The open structure design was chosen no only for these reasons, but also because of its lower cost. In addition, its simple design provides a greater opportunity for adapting modifications for future testing and evaluations. [Ref. 1: pp. 77-82]

Table I lists the open structure radio controlled helicopter available in prefabricated model kits.

TABLE I

Radio Controlled Helicopter Model Kits

Model Kits	Engine Size
American Super Mantis	40
GMP Cobra	40
GMP Competition Custom	60
GMP Competition Pro	60
Hirobo Falcon 555	40
Hirobo Falcon 808	60
Kalt Baron KBH-20	28
Kalt Baron KBH-50	60
Kalt Baron KBH-60	60
Schluter Super Mini-Boy	40
Schluter Custom Heli-Boy	60
Schluter Heli-Star	60
Schluter Superior	60

When deciding on which model of helicopter to construct, one must realize that all helicopter models are not alike. Therefore, the cost and/or size of the helicopter alone should not be used in the selection process. Each model helicopter company usually has different design aims or philosophy and may choose to emphasize a particular flying characteristic or item of equipment in a particular model, as evidenced by the different models listed by most of the companies in Table I. The helicopter which best suits one's needs should be chosen.

The Schluter Heli-Star was chosen as the model kit to be constructed because it is one of the newer model helicopter designs. It is a good choice for the novice through expert. Being a larger and heavier helicopter, it is more stable in hover but has complete aerobatic capability. The time proven mechanics of its predecessor, the Heli-Boy, have been refined and enhanced. The main rotor head is a thrust bear-inged and variable dampened rotor head with trimable Hiller control paddles. The wood parts and aluminum tail fin are pre-cut. It offers a tail boom support and anti-crush tail boom mounts. The Heli-Star has a machined clutch bell with changeable gear and autorotation mechanics included as standard features. It offers a double sided takeoff bevel gear tail rotor drive and feather light molded tail rotor blades with a new airfoil design. The push rods and guides are pre-made and utilize snap and ball links. All metal parts are pre-finished. It utilizes a no-play O-ring swash plate center ball and delrin bearinged control mixer and bell-cranks. An injection molded cyclone fan housing and a visual 20-ounce fuel tank is also provided. The canopy is aerodynamically clean and shrouds the mechanics and radio control equipment.

An engine is not provided with the Heli-Star model kit, but a size 60 gas operated piston engine is recommend for optimum performance. Table II lists the size 60 engines considered to power the Heli-Star model helicopter.

TABLE II

Size 60 Helicopter Engines

Enya 60XFII
Enya 60XFIII
Enya 60XLF
Fox 60 Eagle III
HB 60 PDP
HP 61 Gold Cup F
OS Max 61 FSR
Webra 61 Blackhead
Webra 61 Speed

The HP 61 Gold Cup F size 60 engine was chosen because of its proven high reliability and high available power. The engine includes an ultra-light piston and rod assembly, schneurle exhaust porting, and hard chrome cylinder sleeves and dykes ring. The black finish is a special thermax treating that increases heat dissipation up to four times that of an ordinary engine. This helps keep the engine running smoothly and allows it to develop full power even under adverse conditions. [Ref. 5] The engine should have enough power to propel the Heli-Star helicopter through any conceivable maneuver. The technical data [Ref. 5] for the HP 61 Gold Cup F engine is shown in Table III.

TABLE III

HP 61 Gold Cup F Engine Technical Data

Bore mm dia	Stroke mm	Capacity ccm	Power HP	Operating Range RPM	Weight oz
24.5	21	9.89	2.03	2200-18500	17.2

The last major item to be considered when building a radio controlled model helicopter is the radio control itself. The radio control normally consists of a transmitter with a transmitter crystal and its own internal battery power source, and a receiver with a receiver crystal, switch harness and a separate battery pack to provide power to the receiver. In addition , one servo per channel is connected to the receiver.

The radio frequency of the radio control can either be amplitude modulated (AM) of frequency modulated (FM), and is governed by the Federal Communications Commission (FCC). The FCC has allocated the 53, 72 and 75 megahertz (MHz) wave bands for aircraft radios. Some radio controls can be used for both airplanes and helicopter models, while other radio controls are specifically designed for use with helicopter models only.

The Heli-Star model kit does not include a radio control. A radio control that has a minimum of four channels is required, with five channels considered optimum. Table IV contains a list of radio controls considered for use in the Heli-Star model helicopter.

TABLE IV

Radio Controls

Control Name	Channels	Type
Airtronics SR4R AM	4	Airplane
Airtronics SR6DR AM	6	Airplane
Airtronics Heli FM	6	Helicopter
Airtronics Heli FM	7	Helicopter
Futaba FP-4L AM	4	Airplane
Futaba 7FGK AM	7	Airplane
Futaba 7FGH S-28 Heli FM	7	Helicopter
JR Century 7 Heli AM or FM	7	Helicopter
JR Unlimited Mark VIII FM	8	Helicopter

The Futaba FP-4L radio control was chosen because of its low cost and because it met the minimum Heli-Star requirement of four channels. It includes digital proportional radio control with servo reversing switches. Both receiver and transmitter utilize rechargeable nicad batteries with a battery level meter furnished with the transmitter. The technical data [Ref. 6] for the Futaba FP-4L radio control is listed in Table V.

Since only four servos are available to control the Heli-star engine, collective pitch, tail rotor pitch, lateral cyclic, and fore and aft cyclic, one servo must

TABLE V

Futaba FP-4L Radio Control

Transmitter FP-T4L

Operating system	2 Stick
Transmitting frequency	72.590 MHz
Modulation system	AM
Power requirement	10.5 Volts
Current drain	120 mA

Receiver FP-R4F

Receiver frequency	72.590 MHz
Intermediate frequency	455 KHz
Selectivity	3 KHz/-3 dB
Range	500m (ground) 1000m (air)
Power requirement	6.6 Volts
Current drain	10 mA
Dimensions	1.6x2.3x0.7 in
Weight	1.7 oz

Servo FP-S28

Control system	+pulse width control
Operating angle	Rotary system, one side 45 degrees or greater
Power requirement	6 Volts shared with receiver
Current drain	10 mA (at idle)
Output torque	48.7 oz-in
Operating speed	0.24 sec/60 degrees
Dimensions	1.59x.79x1.59 in
Weight	1.87 oz

control two functions. Normally the engine throttle and the collective pitch are controlled by the same servo. In order to accomplish this a differential linkage must be installed between the engine throttle and the collective pitch control rods. The differential linkage allows the control stick to be increased or decreased causing a corresponding change in the engine throttle control and the collective pitch control such that the engine speed remains fairly constant despite the increased load on it. [Ref. 1: pp. 93-95]

In addition, a tail rotor compensation device should be installed. This is mandatory if no electronic gyrostabilization control device is installed. The tail rotor compensater allows the tail rotor servo to alter the tail rotor pitch separately. It also allows the tail rotor pitch to be adjusted when the throttle/collective pitch servo is operated. This adjustment counteracts the changes in torque and engine output to keep the helicopter on its correct heading. [Ref. 1: pp. 95-96]

Although not a necessity, a gyrostabilizer provides stability to the helicopter which reduces the workload of the radio controlled pilot. Since this would be especially helpful to the beginner pilot, a Kraft KG-1 Super Gyro was obtained to be used as a yaw damper (stabilizes the tail rotor servo) for the Heli-Star model helicopter.

The Kraft gyrostabilizer employs a control method called the stick priority system. With this system the gyrostabilizer responsiveness is maximum when the tail rotor radio control stick is at or near neutral, and is automatically lowered as the stick is moved away from the neutral position. Since the stick signal has priority, the required yaw position can be obtained with the tail rotor radio control stick alone and advantage taken of the gyrostabilizer's full performance. [Ref. 7] The technical data [Ref. 7] for the Kraft gyrostabilizer is listed in Table VI.

TABLE VI

Kraft KG-1 Super Gyro

Power requirement		5 Volts shared with receiver
Current drain		120 mA
Dimensions:	Gyrostabilizer	1.68x1.43x1.24 in
	Amplifier	1.995x1.12x.69 in
Weight		2.875 oz

Since the Kraft gyrostabilizer has a large current drain and is connected to the receiver power supply, a 1000 mA nicad battery pack was obtained to power the entire receiver system. The Kraft gyrostabilizer also has a separate power switch. When the gyro is switched off, the servo that is plugged into the gyrostabilizer amplifier can still be controlled , but there will be no stabilization. [Ref. 7]

B. ASSEMBLY OF THE HELI-STAR MODEL HELICOPTER

The assembly of the Heli-Star model helicopter was accomplished in 14 steps. Figures A.1 - A.11, A.13 and A.14 [Ref. 8], and Figure A.12 [Ref. 2: p. 137, Fig. 9-27] associated with these steps can be found in Appendix A. Table VII lists the basic tools and equipment required to construct and set up the Heli-Star model helicopter.

TABLE VII

Tools and Equipment

Provided with Kit	Additional Equipment Required
1.5 mm Allen Key*	Socket Wrench with 5.5, 7.0, & 8.0 mm Sockets*
2.0 mm Allen Key*	Electric Drill with assorted drill bits
2.5 mm Allen Key*	Lubricating oil
3.0 mm Allen Key*	Fine Grained Sandpaper
Grease	Knife
Loctite*	Needlenose Pliers
	Schluter Pitch Gauge*
	Schluter Flybar Lock*
	Hot Stuff Glue

1. Step 1

The sequence of building steps starts with the assembly and attachment of the lateral and longitudinal cyclic levers to the outsides of the two main side frames according to detail-drawings D1 and D2 of Figure A.1. The levers should be free of play but move smoothly. The landing gear is then assembled and the two sides of the main frame attached as shown in Figure A.2.

2. Step 2

The main rotor drive gear and swash plate with bearing assemblies are assembled in a exact sequence on the main rotor shaft according to Figure A.3. This assembly is then aligned absolutely vertical and attached between the two main frame side parts as shown in Figure A.4.

3. Step 3

The bevel gear drive for the tail rotor is assembled and mounted between the two main side frames according to Figure A.4. The tail support and horizontal stabilizer are attached to the tail tube, which is in turn mounted between the two main side frames behind the bevel gear drive as shown also in Figure A.4. The bevel gear must be aligned with the main rotor drive gear without play but it must run smoothly. The tail tube must be routed directly to the rear of the main frame.

4. Step 4

Because the HP 61 Gold Cup engine drive shaft is too large in diameter, the cooling fan wheel has to be bored out using a lathe before it could be attached to the engine drive shaft. The cooling fan wheel is then checked at point X1 as shown in Figure A.5 and adjusted for true rotation with maximum tolerance of 5/100 mm. When the cooling fan wheel rotates completely true, then the clutch and starter shaft are fitted to the cooling fan wheel. These two are then also checked at points X2 and X3, respectively, as shown in Figure A.5 and adjusted as required for true rotation. Their maximum tolerance is also 5/100 mm.

5. Step 5

The engine clutch bell, engine drive gear bearings and starter cone are next fitted to the starter shaft according to Figure A.6. The engine with the assembled starter shaft is then attached to and aligned perfectly vertical with the two main side frames as shown in Figure A.7. The engine drive gear must run play free but smoothly with the main rotor drive gear.

6. Step 6

The toggle lever, eye bolt and the lower part of the collective pitch linkage are assembled and installed between the two main side frames according to detail-drawing D1, Figure A.1. The cooling fan housing is fitted to the main frame with the cooling fan housing extension cut as shown in Figure A.7 according to the engine type used. The extension should be positioned at least 5mm away from the engine. The muffler, which is not included in the kit model or with the engine and must be obtained separately, can be added to the engine at this time. A Heli-ball muffler was used instead of the recommended Schluter muffler because it was less expensive.

7. Step 7

The main wooden support frame is assembled and inserted into the front of the main metal frame according to detail-drawing L1, Figure A.8. The cooling fan housing with its extension is attached securely to both the front and the back of the main metal frame.

8. Step 8

The tail rotor rear is assembled next according to Figure A.9,, insuring that the two different bevel gears inside are installed correctly. The gear box should be filled with grease. After it is painted, the tail fin is mounted to the tail rotor gear box. The tail drive shaft is installed first into the tail rotor gear box and then through the tail tube into the front bevel gear drive attached to the main frame. The tail rotor gear box is then clamped securely in place.

9. Step 9

The tail rotor hub with blade holders and control parts are assembled next according to Figure A.9. With the tail rotor blades added, the complete tail rotor is balanced as shown in Figure A.9 and finally mounted onto the shaft of the tail rotor gear.

10. Step 10

The fuel tank is installed according to Figure A.10. The distance for the tank to the engine muffler should be a minimum of 10 mm.

11. Step 11

The main rotor hub is then assembled according to Figure A.11. The mixing lever is attached to the blade holders which in turn are mounted on the main rotor hub. The stabilizer bar with its balancing weights and control paddles are then added. The U-lever is added along with various control rods.

12. Step 12

The wooden rotor blades are first sanded and then individually covered with a thin, self-adhesive plastic covering. The blades are next attached to the blade holders. The completed main rotor system is then balanced as shown in Figure A.12 and attached to the main rotor drive shaft.

13. Step 13

Positions for the servos are cut out of the two wooden servo trays as shown in detail-drawing L2, Figure A.13. The trays, along with the wooden fire wall with cut-out positions for switches are glued to the main wooden frame. Since only four servos are used, a tail rotor differential linkage device must be assembled and installed on the main wooden frame. After the canopy has been cut out, glued and painted, it is fitted to the helicopter. A strong medium-sized rubber band is used to secure it in place later.

14. Step 14

The four servos, gyrostabilizer with amplifier, radio receiver, battery pack, switched and a tail rotor compensater are now installed according to Figure A.13. The gyrostabilizer should be installed at or near the center of gravity with its top surface perpendicular to the yaw axis. The servos are normally connected directly to the receiver. However, with a gyrostabilizer installed the tail rotor servo is connected to the amplifier and then to the receiver. The battery and especially the receiver should be wrapped in foam and secured to the front of the bottom wooden servo tray. Various push rods are installed which connect the servos and the control linkages of the helicopter and engine. The assembled model helicopter should now be similar in appearance to Figure A.14 and is almost ready to fly.

C. HELI-STAR SETTINGS

After assembly, the Heli-Star model helicopter should be set up accordingly.

1. Setting 1

The center of gravity of the model, with a half filled fuel tank and complete equipment, can be checked by lifting up on the main rotor stabilizer bar. The helicopter should tilt down approximately two to three degrees.

2. Setting 2

The maximum tilt of the swash plate is ±15 degrees. This corresponds to ±8 mm travel of the rods leading to the swash plate and ±12 mm travel of rods to the servos.

3. Setting 3

Pitch reactions can be set by using one of the three positions on the U-lever of the main rotor hub as shown in detail-drawing A, Figure A.13. The inner position is for normal pitch reaction and is used for simple aerobatic flight. The middle position is for increased pitch reaction and is used for autorotative flight. The outer position is for extreme pitch reaction and is used for inverted flight. The preferred position is the middle position.

4. Setting 4

The tail rotor setting for hovering flight should have a middle value of approximately five degrees. The entire range for the tail rotor setting should be from approximately +12 degrees to approximately -3 degrees.

5. Setting 5

Table VIII [Ref. 1: p. 93] lists the radio control stick setting and corresponding engine throttle setting and collective pitch setting.

TABLE VIII

Main Rotor Pitch and Corresponding Settings

Stick Setting	Pitch Angle	Engine Setting
Minimum	1 degree	Idle
20%	2 degrees	30%
40%	3 degrees	60%
60%	4 degrees	90%
80%	5 degrees	Full throttle
Maximum	6 degrees	Full throttle

In addition, the main rotor blades should have a slight, but identical positive coning angle [**Ref. 1: pp. 68-71**]. The Schluter Universal Pitch Gauge should be used for setting and checking the pitch of the main rotor and tail rotor blades insuring that the pitch settings are identical for each pair of blades. The helicopter should now be ready for its final check out before flying.

V. LEARNING HOW TO FLY A RADIO CONTROLLED MODEL HELICOPTER

A. ACCESSORIES

Once the model helicopter is assembled, the following accessories are needed for starting and flying the Heli-Star model helicopter.

1. Electric Starter

A 12 volt DC electric starter is required to start the Heli-Star helicopter with the HP 61 Gold Cup engine installed. A Sullivan Deluxe starter with a Schluter starter extension was chosen because it is a high torque/ high RPM direct drive starter. The starter also offers a hand guard and and 'instant on' strip switch for finger tip control. The extension, which is adapted for the Heli-Star starter cone, allows the starter to be held above the rotor head, thus reducing any chance of damage to the rotor head. A 12 volt DC battery is required as a power source for the starter. The connecting leads from the battery to the starter should be kept as short as possible to reduce the chance of voltage drop.

2. Fuel

The choice of fuel depends on the type of motor, motor settings, choice of glow plug, the type of application and the climate conditions at the time [Ref. 1: p. 127]. The fuel must contain a lubricant to lubricate the HP engine. A 5% nitro-95% methanol/lubricant mixture was chosen. The nitro provides extra power but is not enough to cause the engine to run rough or overheat. The fuel is normally obtained in one gallon plastic containers.

3. Fuel Pump

A fuel pump is required to transfer fuel from the one gallon fuel container to the Heli-Star fuel tank. A Six Shooter manual fuel pump was chosen for this task. It straps directly to the side of the gallon fuel container, but a onetime modification of the fuel cap is required. The pump provides 6/10 ounce per turn of the manual pump crank [Ref. 9].

4. Glow Plug

The HP 61 Gold Cup engine requires a long reach cold glow plug with a 1.5 volt dry cell battery as a external power source. A Fox Long Reach Glo-plug with idlebar is used. The plug is brought to glow initially by the use of the 1.5 volt battery. After the engine has been started, its RPM becomes sufficient so that the external power source is no longer needed to keep the plug glowing. In the Heli-Star design, it is difficult to attach the external power source to the glow plug directly. A plug extension wire was developed by attaching a semi-permanent copper alligator clip to the installed glow plug. The other end of the alligator clip was attached to a plastic coated wire. The wire was then extended to below the bottom of the fuselage where a portion of the plastic coating was removed allowing easy access for connecting the external power source. The 1.5 volt battery uses two plastic coated copper wires with alligator clips for starting the engine. One wire (positive) is connected to the glow plug extension wire while the other wire (negative) is grounded to the helicopter metal frame.

5. Training Gear

Although not required, an extra wide-based landing gear is recommended for initial training. There are a number of training gear arrangements available, but the best appears to be a float kit. The floats provide a relatively wide-spaced landing gear which prevents the helicopter from turning over and damaging the rotor blades. The floats can be used on grass, hard surfaces and water. The air in the floats act as a cushion reducing the effects of a hard landing. The additional weight of the landing gear on the bottom of the helicopter increases the stability of the helicopter. When the floats are added to, instead of replacing the Heli-Star landing skids, the helicopter is raised higher off the ground increasing the center of gravity (a disadvantage), but reducing the chance of tail rotor damage on landing and also reducing the in ground effects on hover. [Ref. 1: p. 151]

6. Miscellaneous

The asterisked equipment of Table VII should be available if any adjustments are required when flying.

B. FINAL CHECK

Prior to flying the following final checks [Ref. 1: pp. 130-131] should be accomplished.

Check over the engine installation, and in particular check that all the engine bolts are correctly fitted and tightened.

Check that the muffler and adapter are fitted correctly and tightened.

Check that the fuel tank is installed in the correct position and is securely held.

Check that the fuel line is not kinked, that it is fitted correctly, and that the fuel filter is not clogged.

Check that the fuel tanks's filler and vent pipes are clean.

Check all push rods, for all four functions and for ease of movement, working from the servos to the mechanics.

Operate all controls to their extremes of travel and check that the push rods etc. cannot jam or rub against any part.

Check that all push rod connections are fitted correctly and that the snap links are fully engaged.

Check all ball links for freedom of movement. If necessary, unsnap the plastic part and apply a drop of oil to the ball.

Check the entire tail rotor system. Disconnect the tail rotor push rod and check its operation by hand. Check over all retaining screws on the tail rotor, including the blade retaining screws.

Check over the main rotor. This includes all rotor blade bolts, all the bolts of the complete mechanical system including the locknuts, and the correct fitting of all control push rods, control arms etc. Bear in mind the high centrifugal force of the rotor blades and take particular care in this area.

Check the rotor blade minimum and maximum pitch settings.

Are the rotor blade tips different colors to aid blade tracking checks?

Check that the entire drive system is securely mounted, rotates freely and the gears mesh correctly. Oil the mechanics or check the grease level in the gear box, topping if necessary.

Are the batteries fully charged?

Are all the other radio controlled system components properly fitted, and isolated from vibration by foam rubber?

Is the aerial correctly deployed and not coiled up in the fuselage?

Is the helicopter's center of gravity still in the correct position or has it shifted as a result of adding additional equipment or detail fittings?

After completing the final checks, the helicopter should be ready to fly.

C. STARTING THE HELICOPTER

First, the fuel tank is filled with fuel. Next connect the electric starter to the 12 volt DC power supply. Without the starter extension installed, ensure that the starter turns in a counter-clockwise direction. Re-install the starter extension. Before switching on the radio system check that the radio frequency is clear. With both transmitter and receiver on, check all four control functions of the helicopter. Also ensure that the gyrostabilizer is functioning. Place the stick controls in their neutral positions except the throttle/collective pitch stick which is positioned full aft. The corresponding trim switch for the throttle/collective pitch control should be placed in the full up position. Connect the wires from the 1.5 volt DC dry cell to the glow plug extension wire and to the airframe. Press the starter extension down onto the starter cone taking care not to damage any parts of the rotor head. Also ensure that the immediate area around the helicopter is clear and safe for starting. While holding on to the rotor blade to prevent turning, switch on the starter switch. Do not operate the starter for more than 15 seconds at a time and allow 1 minute between starts. After the engine starts, slowly disengage the electric starter from the starter cone, again taking care not to damage the rotor head. While still preventing the rotor blade from turning, remove the 1.5 volt DC battery wires from the helicopter. Next, pick the helicopter up by the stabilizer bar and move it along with the radio transmitter control to the take-off or hover area. When releasing the stabilizer bar be careful of the rotor beginning to turn. The rotor RPM can now be increased to a moderate speed, but not to take-off speed yet.

D. ROTOR CHECKING AND BLADE TRACKING

If the rotor is correctly balanced, the rotor should rotate smoothly without any severe vibration. If not, the helicopter will have to be shut down and the main rotor system re-balanced.

The blade tracking check is next. Correct blade tracking means that the rotor blades are spinning in the same plane [Ref. 1: p. 140]. Here is where the differential marking of the rotor blade tips is helpful. The spinning blade tips are observed form one side being careful not to get to close to the blades. If the blades are not in the sames plane or more than 10 mm apart, the rotor blade pitch angle has to be altered by either reducing the pitch in higher blade or increasing the pitch in the lower blade. The pitch is adjusted by changing the length of the blade connecting push rod.

E. BEFORE TAKE-OFF CHECK

Before taking off the following checks [Ref. 1: p. 142] should be conducted.

Is there enough fuel in the tank?
Is the transmitter aerial fully extended?
Is the receiver aerial fully deployed?
Is the lateral swashplate control working?
Is the fore and aft swashplate control working?

Is the tail rotor control working?
Is the throttle/collective pitch control working?
Is anybody standing too close for safety?
Is the take-off area free?
Are any other models likely to take off or land?
If all is well, the helicopter is now ready to be flown.

F. HOVERING

Before attempting to hover, the radio control pilot should position the front of the helicopter into the wind. The pilot should be located almost directly behind the helicopter but slightly to the right or the left.

By advancing the throttle/collective pitch stick control slowly, the main rotor and tail rotor speeds are also increased. Also when ever the throttle/collective pitch control is increased or decreased, there is a corresponding change in torque. If this control is operated slowly and smoothly, the torque variations will stay within limits and can be recognized early enough to be compensated for. The radio control pilot should acquire a comfortable feeling for these changes of torque.

By advancing the throttle/collective pitch control, eventually the helicopter will reach a point where it will want to rotate and slide around on the ground. When this point is reached, the helicopter is considered light on its skids. The throttle should not be advanced any further at this time.

If the tail rotor is set up as specified, the tail rotor trim control should be be adjusted to trim out the rotation of the tail. If the tail rotor trim control does not have enough movement to trim out the rotation, the tail rotor linkage or the servo throw will have to be corrected. By maintaining the nose of the helicopter into the wind, the helicopter will exhibit a weather-cocking effect which will also help in controlling the tendency of the tail rotor rotate. In trying to control the helicopter, the radio control pilot should watch the center of the helicopter and not the tail. The pilot should remember that to turn the helicopter to the left, the nose of the helicopter should move to the left and to turn the helicopter to the right, the nose of the helicopter should move to the right. Only when the tail rotor is under complete control should the pilot think about controlling the main rotor system or altering the direction of flight. [Ref. 1: p. 161]

When the radio control pilot feels comfortable in controlling the tail rotor, the throttle/collective pitch stick control should then be advanced one notch at a time until the helicopter has the tendency to tilt to one side or the other. The throttle should not be advanced any further at this time. The cyclic control trims, both lateral and/or longitudinal, should be adjusted to cancel out this tendency. If the cyclic trim controls do not have enough movement to trim out this tendency, the appropriate cyclic push rod linkage or servo throw should be adjusted. [Ref. 1: p. 166]

No attempt to lift the helicopter off the ground should be made until the radio control pilot is comfortable with the tail rotor and cyclic stick controls. If the pilot feels out of control, a simple, quick reduction of the throttle/collective pitch control stick will correct the problem.

With the helicopter light on the skids and in control, the throttle/collective pitch control stick is further advanced one notch at a time until the helicopter justs lifts off the ground. Due to the ground effect, the helicopter is likely to move off in one direction or another. The radio control pilot must be able to recognize this movement and apply the appropriate counter-control to the main rotor and/or tail rotor to correct the movement and maintain the helicopter over a particular spot or in a particular area. [Ref. 1: p. 167] This may be difficult and frustrating at first. Basically the pilot should remember that all movements of the helicopter are controlled by first stopping the movement, then initiating a movement in the opposite direction, then stopping the movement again and, finally, maintaining the new position [Ref. 1: p. 173]. Again, if the pilot feels out of control a simple, quick reduction of the throttle/collective pitch control stick will correct the problem. These first flights at attempting to hover and the corresponding control movements should be repeated over and over. After successfully completing these flights, the radio control pilot should have developed a feeling for arresting and correcting the helicopter.

The radio control pilot should now attempt to hover the helicopter at 1 to 6 feet. The pilot should notice that as the hover height increases, the ground effect decreases and the helicopter is easier to control. The helicopter can be landed by slowly reducing the throttle/collective pitch control stick while maintaining the helicopter into the wind. If the pilot feels out of control, the previous simple, quick reduction of the throttle/collective pitch control stick should not be attempted as it could cause the helicopter to crash into the ground. It is better to try to maintain altitude and apply the appropriate corrections even if the helicopter moves around the entire flying field. If the helicopter does move around, the pilot should also move with it keeping the helicopter to the front. [Ref. 1: pp. 167-171]

As the pilot gains more experience and confidence, the hover height can be increased to 10 to 20 feet. The helicopter can be landed from this altitude by slowly and smoothly reducing the throttle/collective pitch control stick to avoid increasing the vertical descent of the helicopter and maintaining the helicopter into the wind. If the vertical descent increases, the corrective action would be to increase the throttle/collective pitch control stick. This could result in a rapid increase in torque with a resultant loss of control of the tail rotor. When in a vertical descent and given the right conditions, the helicopter can also drop into its own rotor downwash. [Ref. 1: pp. 171-172]

Again with increased experience and confidence, the pilot can try flying forward into the wind for 20 to 30 feet. The pilot can also try moving to the left or to the right and back again while maintaining the nose of the helicopter into the wind. [Ref. 1: p. 171]

These hovering flights should also be repeated over and over again until the radio control pilot feels proficient enough to advance to circuit, autorotative and/or aerobatic flight. Reference 1, pages 173-196 discusses advance training in these three flight areas.

G. POST-FLIGHT CHECKS

After landing, reduce the throttle to engine idle and reduce the throttle trim to the full down position. If the engine is trimmed correctly, it will shut off and the rotor will slow down and stop on its own accord. The following post-flight checks should then be accomplished.

Clean the oily residue from your model, but be careful not to bend the push rods or alter any settings [Ref. 1: p. 145].

Check that all mechanical parts are still in order. Check in particular that the push rods and other metal parts do not show signs of rubbing. A black oily smear on aluminum is a indication that parts may be loose. Check that the exhaust is still secure, the skids have not come loose and no bolts are loose or have come undone. [Ref. 1: p. 145]

If, when cleaning and checking, a defect is discovered, it is important to remedy the problem before flying again.

VI. HOVER TESTING

One purpose of the hovering performance tests is to evaluate the main rotor performance in order to predict the hovering performance over a wide range of operating conditions. The tests can also help researchers utilize the results to validate design assumptions, compromises, and the basic equations. [Ref. 10: p. 5-1] Hovering performance test may be accomplished on a vertical thrust stand, in tethered flight or in free flight [Ref. 10: p. 5-4].

A tethered hovering performance test will be used to investigate the performance characteristics of the Heli-Star model helicopter. The test is to be accomplished by using the Heli-Star model helicopter, a Chatillon scale and a variable light strobe. One end of a tether is to be attached to the bottom of the model helicopter as close as possible to the center of gravity. The other end would be attached to the Chatillon scale which would in turn be secured to the ground. By lifting the model helicopter vertically off the ground to the limits of the tether, its vertical thrust can be measured directly using the Chatillon scale. The rotor RPM can be determined at the same time by using the variable light strobe.

Various thrust and rotor RPM readings will be measured at different altitudes, both in and out of ground effect. The thrust coefficient, CT, can be calculated according to the equation:

$$CT = T/(rho \cdot A \cdot (\text{Rotor Speed})^2) \qquad \text{(eqn 6.1)}$$

where: T = Vertical thrust (lb)

A = Areas of the rotor disk (ft^2)

rho = Air density (slugs/ft^3)

Rotor Speed = 2•pi•(RPM/60)•Radius (ft/sec)

This data will be reduced, plotted graphically and compared with known data trends and performance characteristics of full-size helicopters.

VII. CONCLUSIONS AND RECOMMENDATIONS

In comparing the radio controlled model helicopter to a full size helicopter, the author found that the similarities far outweigh the differences. Therefore, the author chose a Heli-Star radio controlled model helicopter with related equipment, constructed it, learned how to fly it and attempted tethered hovering performance tests, to determine if a radio controlled model helicopter could be used in experimental research at college or university level.

The author found that the technology of the radio controlled model helicopter is not as advanced as the current full-size helicopters for two main reasons. One is that most radio controlled model helicopter pilots are satisfied with what they have, so there is not a great demand for any new or improved technology. The other reason is that some of the complex equipment of the full-size helicopters can not be reduced economically and/or functionally. The latter reason could be a definite hindrance to conducting this type of research.

The use of data instruments is limited in a radio controlled model helicopter. The size of the model restricts the amount of space available for installation of instruments. Also some instruments can not be reduced in size for use in a model helicopter and still provide accurate data. This lack of instrumentation on a model helicopter reduces the amount of data available to validate research requirements.

The author validated the assumption that the Heli-Star model helicopter is currently near the top of the line in state-of-the-art design and performance for radio controlled model helicopters. The Heli-Star's basic parameters are listed in Table IX.

TABLE IX

Heli-Star Parameters

Main Rotor Radius	2.17 ft
Number of Main Rotor Blades	2
Rotor Height Above Ground With Floats	1.47 ft
Main Rotor Cord	.211 ft
Main Rotor Blade Twist	0°
Tail Rotor Radius	0.44 ft
Number of Tail Rotor Blades	2
Tail Rotor Cord	.091 ft
Tail Rotor Blade Twist	0°
Tail Length	2.59 ft
Weight (without fuel, with floats)	12.2 lb

The Heli-Star kit does not, however, contain detailed instructions on assembly. This caused some confusion and time delays for the author, who was not familiar with radio controlled model helicopter assembly techniques. If possible, a potential builder should obtain and study the different individual model helicopter building plans of each of the manufacturers to see which model is more understandable to the builder and, therefore, easier to assemble.

The HP Gold Cup Engine performed satisfactorily without any problems. However, the engine drive shaft was too large in diameter and the cooling fan wheel had to be bored out using a lathe before it could be attached. If no lathe is readily available, a potential builder should consider using another engine only after insuring that the dimensions of the new engine drive shaft will fit the cooling fan wheel.

The Kraft KG-1 Super Gyro was helpful in stabilizing the yaw of the Heli-Star model helicopter. However, the Kraft wire connectors are not compatible with the Futaba FP-4L radio control. Unless an adapter can be obtained or the builder is familiar and has the equipment to splice a Futaba wire connector to the Kraft system, a Futaba gyrostabilizer or any other gyrostabilizer with compatible connectors should be used.

The Futaba FP-4L four channel radio control was adequate in controlling the Heli-Star model helicopter. However, the Futaba FP-4L was marginally adequate in adjusting and trimming the Heli-Star control mechanics. The use of a four channel radio control required both the engine throttle and the collective pitch controls be operated by the same servo. In order to accomplish this, a differential linkage between the engine throttle and collective pitch control was added to the model. The chief difficulty in controlling a helicopter, such as the Heli-Star, with collective pitch control is that of matching the engine output to the rotor's setting, and the load on the motor resulting from pitch changes [Ref. 1: p. 94]. When using the differential linkage, the engine throttle and collective pitch controls could not be correctly adjusted for optimum control and performance. If one control was adjusted correctly, then the other would not be and vice versa.

The addition of a fifth servo with a corresponding five channel radio control would help eliminate this control problem. Two separate servos would be used to control the engine throttle and the collective pitch. Each servo could be adjusted separately for optimum control and performance. Instead of the engine throttle and the collective pitch being controlled separately by the pilot and making it even harder for the pilot to control, the two control functions would be connected to the same control stick and, therefore, they would respond to the same control signal.

When flying a radio controlled model helicopter, all the control functions should be correctly trimmed and adjusted. In order to adjust the Heli-Star with the Futaba FP-4L radio control, the pilot had to stop the helicopter and manually adjust the control mechanics each time an adjustment was required. This could be very time consuming if the adjustment did not correct the problem and the controls had to be readjusted again and again.

Recently radio controls are being produced which are designed specifically for helicopter flying. Although more expensive than the basic airplane radio control, such as the Futaba FP-4L, these radio controls allow the pilot to make control adjustments electronically in a variety of ways without having to stop the helicopter and physically work on it. The need for mechanical mixers and compensaters is eliminated. However, a total of five servos are now required. One servo is used for main rotor pitch control, one for engine throttle control and one for tail rotor pitch control in addition to the two servos required for lateral and fore and aft control. When the pilot operates the collective pitch control to lift the model, the main rotor pitch is increased and the throttle and tail rotor pitch are electronically adjusted automatically.

Additionally, a FM radio control should be chosen instead of an AM one. With the FM radio control there is less chance of radio interference from other outside radio sources. It is also less susceptible to interference from signals produced from metal-to-metal contact/vibration of the model helicopter itself.

All the reversing, trimming and adjusting controls on the helicopter radio control are certainly a help to the expert, but their inclusion complicates the transmitter greatly, it is not recommended for a beginner pilot by Dieter Schluter [Ref. 1: p. 97]. It is felt by this author that complexity and the increased cost of the helicopter radio control could be easily overcome by the time saved and the ease in making helicopter control adjustments, even if the pilot is a beginner.

The tethered hovering performance test could not be accomplished as the author did not become proficient enough to accomplish the precise hovering required by the test. With a few exceptions, it usually takes two to three years for a pilot to really master the model helicopter [Ref. 1: p. 147]. Even though the author was proficient at flying full-size helicopters, it did not aid immensely in learning how to fly a radio controlled helicopter. It was as if the author was just learning how to fly a helicopter.

The use of a radio controlled model helicopter to conduct free flight performance and tethered hover testing would not be feasible at the college or university level unless a permanent experienced pilot was available to fly the model helicopter during testing.

Testing could possibly be accomplished using a training stand. A training stand incorporates a universal joint for mounting the helicopter at its center of gravity. This universal joint can be set to limit lateral and pitch movement, allowing only vertical movement. A test could possibly be developed to measure the vertical thrust produced at a particular rotor RPM for a particular rotor blade. By changing the particular rotor blade size and/or shape and evaluating the results, a determination could be made as to which type of rotor blade design produces the best vertical lift.

Finally, a radio controlled model helicopter on a training stand could be an invaluable training aid to an instructor teaching a class on basic helicopter theory or performance. Safety would have to be incorporated into any classroom presentation or laboratory.

APPENDIX A

HELI-STAR DETAIL ASSEMBLY PLAN

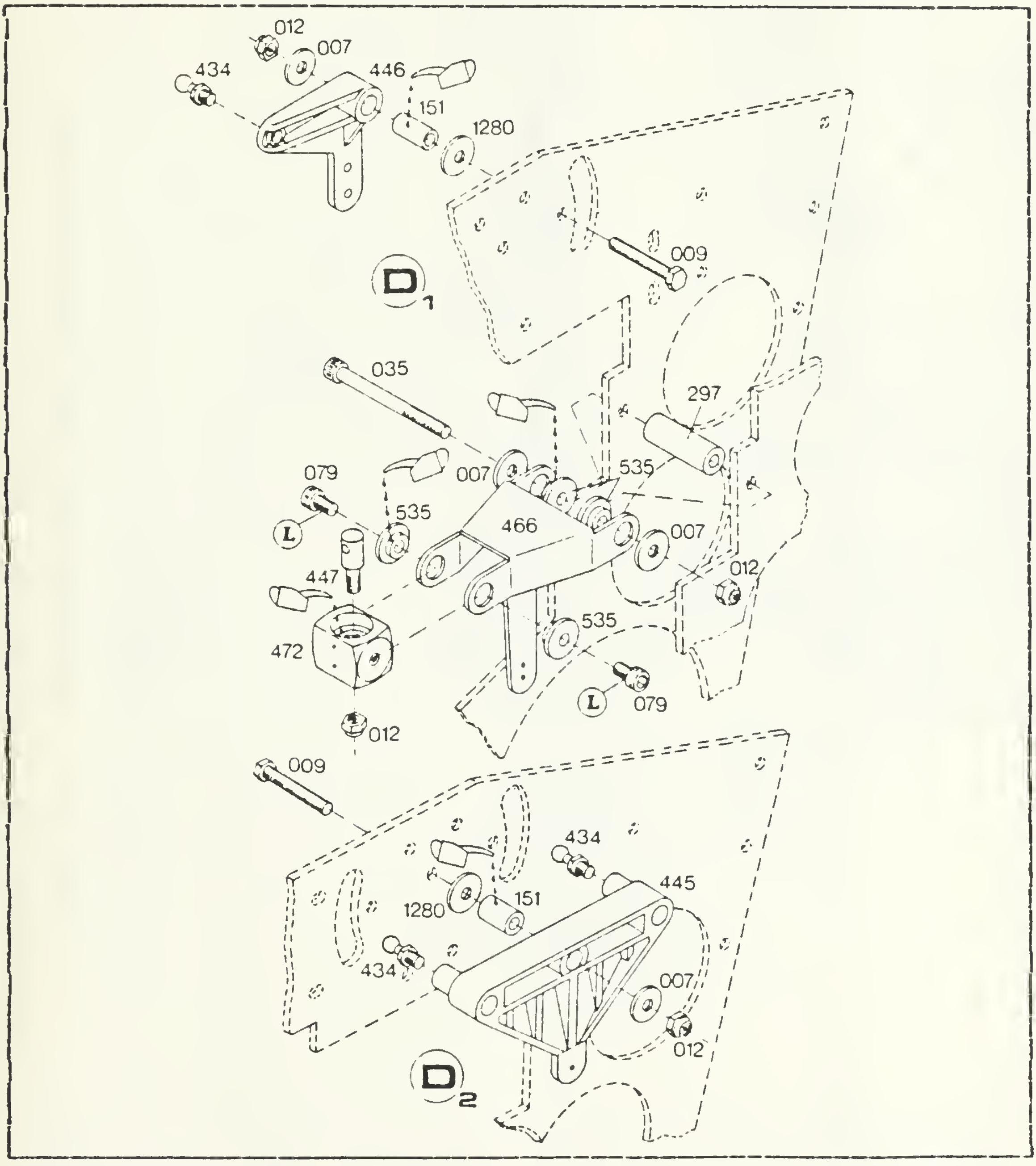

Figure A.1 Lateral & Longitudinal Cyclic Lever Assembly

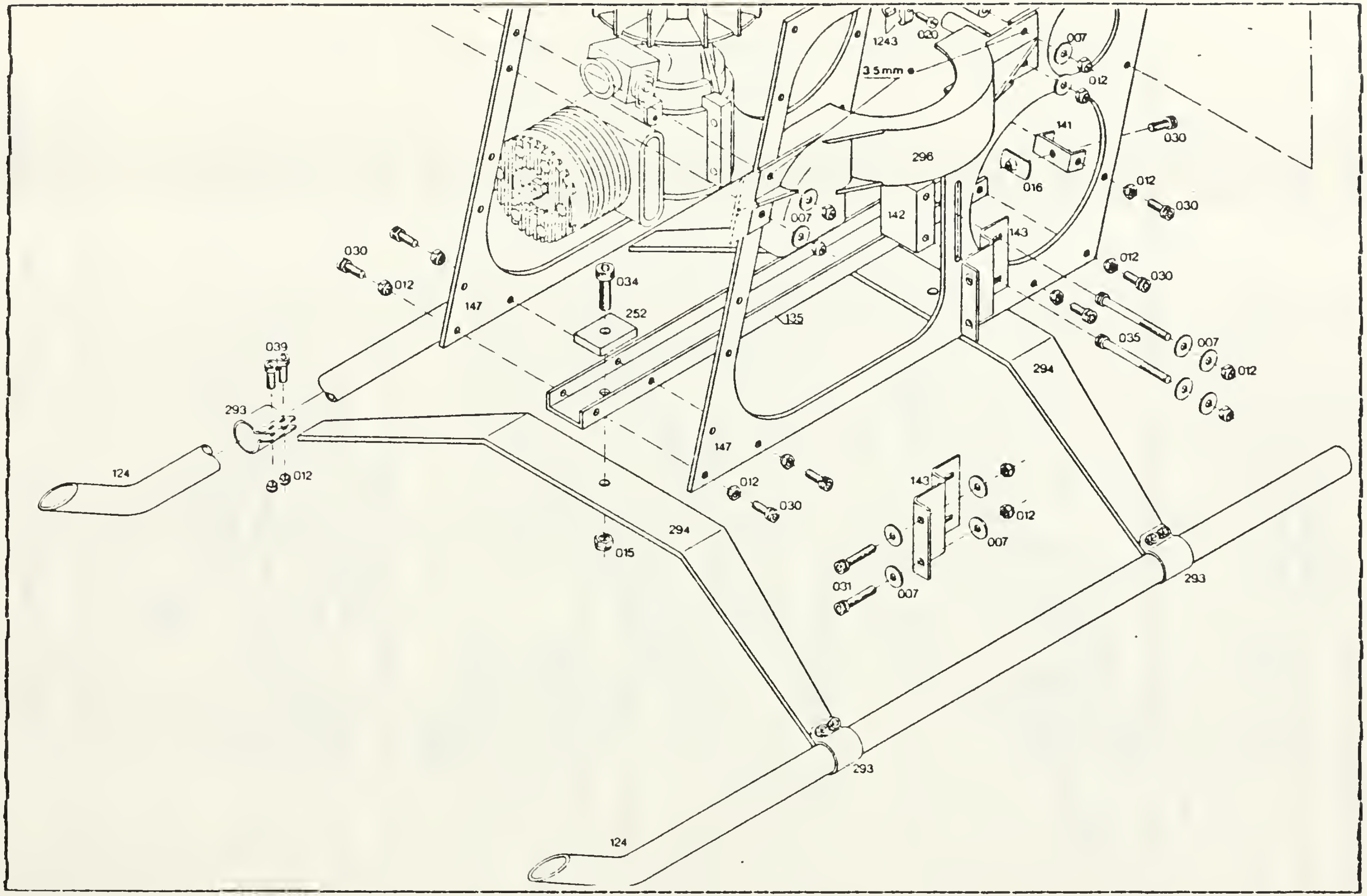

Figure A.2 Landing Gear & Main Frame Assembly

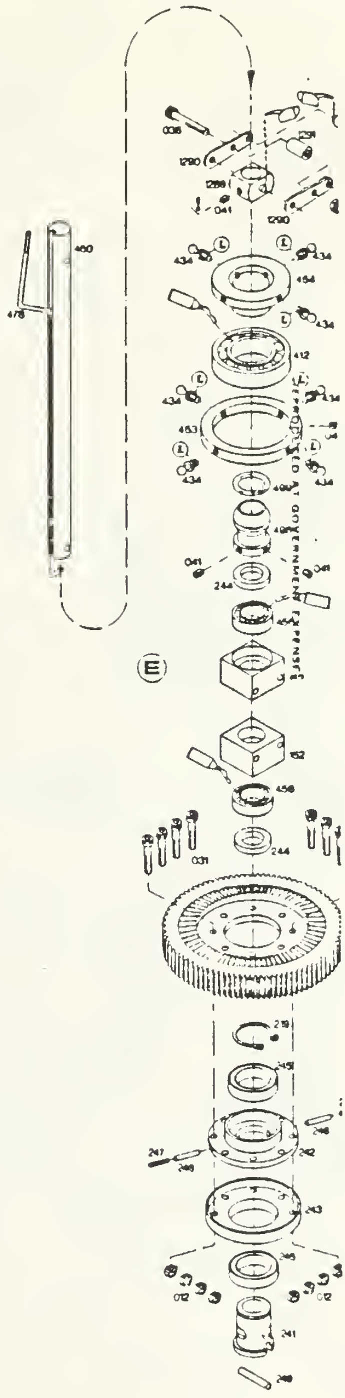

Figure A.3   Main Rotor Drive Gear & Swash Plate Assembly

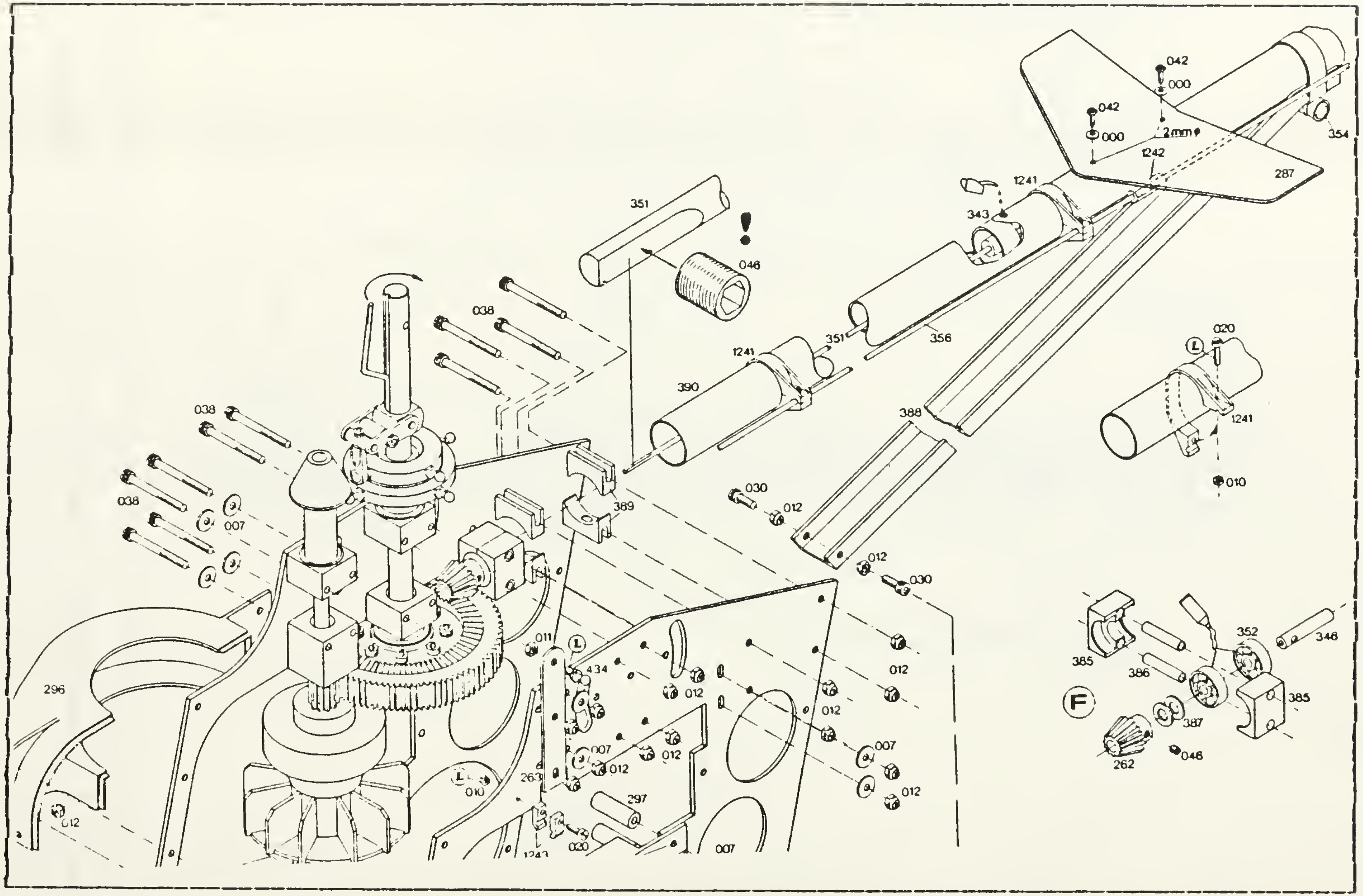

Figure A.4 Main Rotor & Tail Rotor Drive Assembly

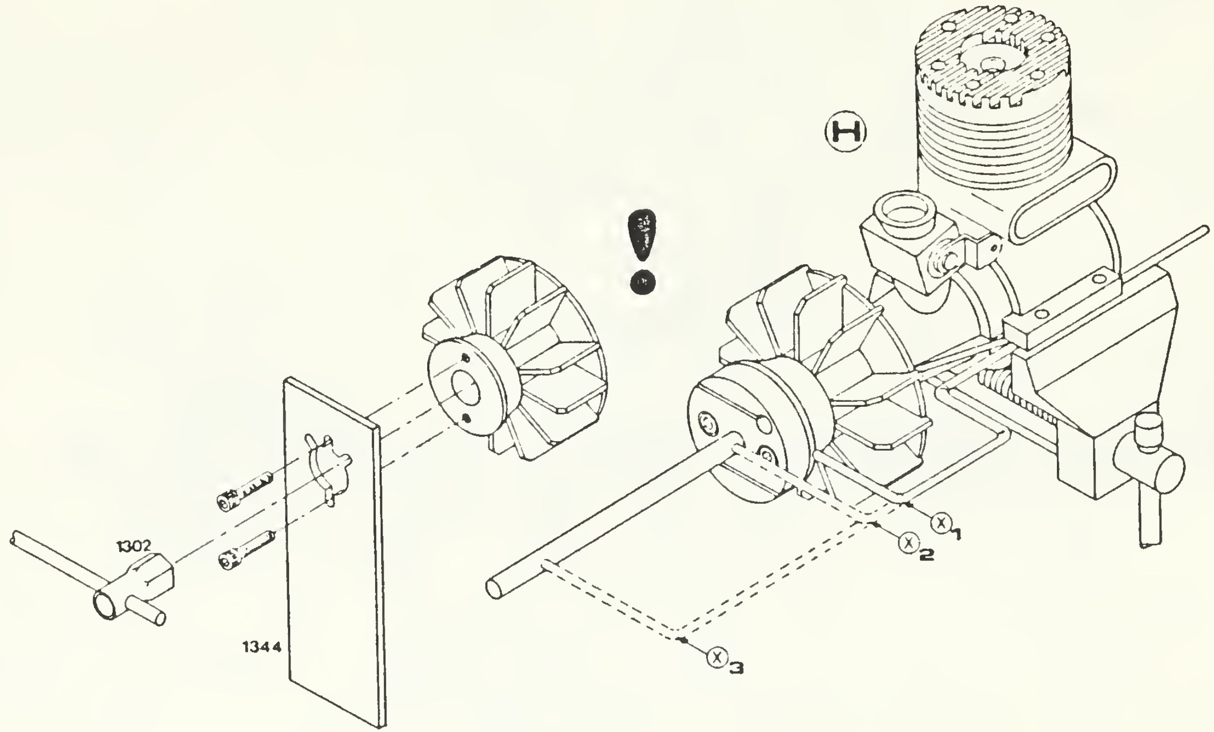

Figure A.5 Cooling Fan, Clutch & Starter Shaft Assembly

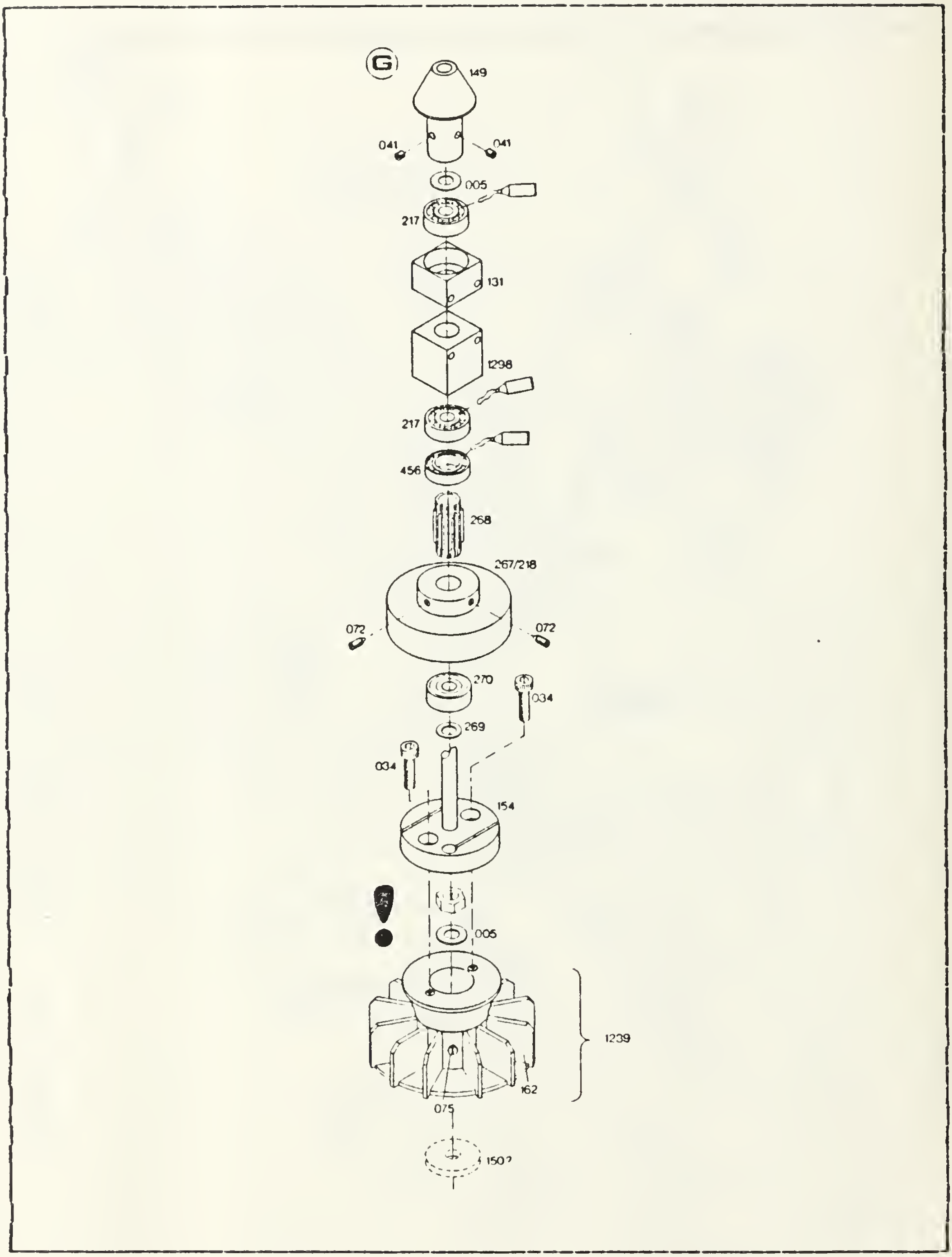

Figure A.6 Clutch Bell & Starter Cone Assembly

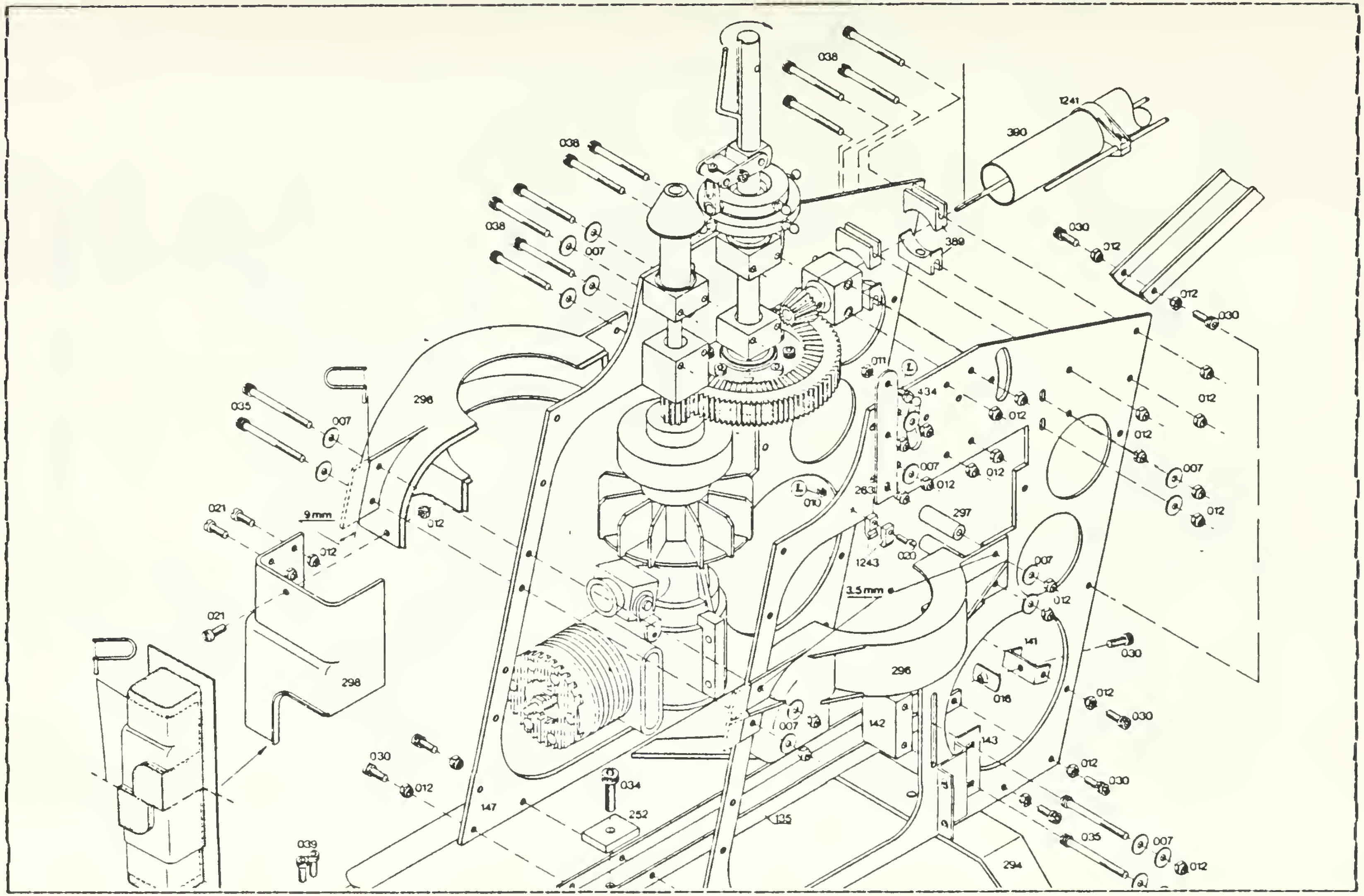

Figure A.7 Engine, Starter & Fan Housing Assembly

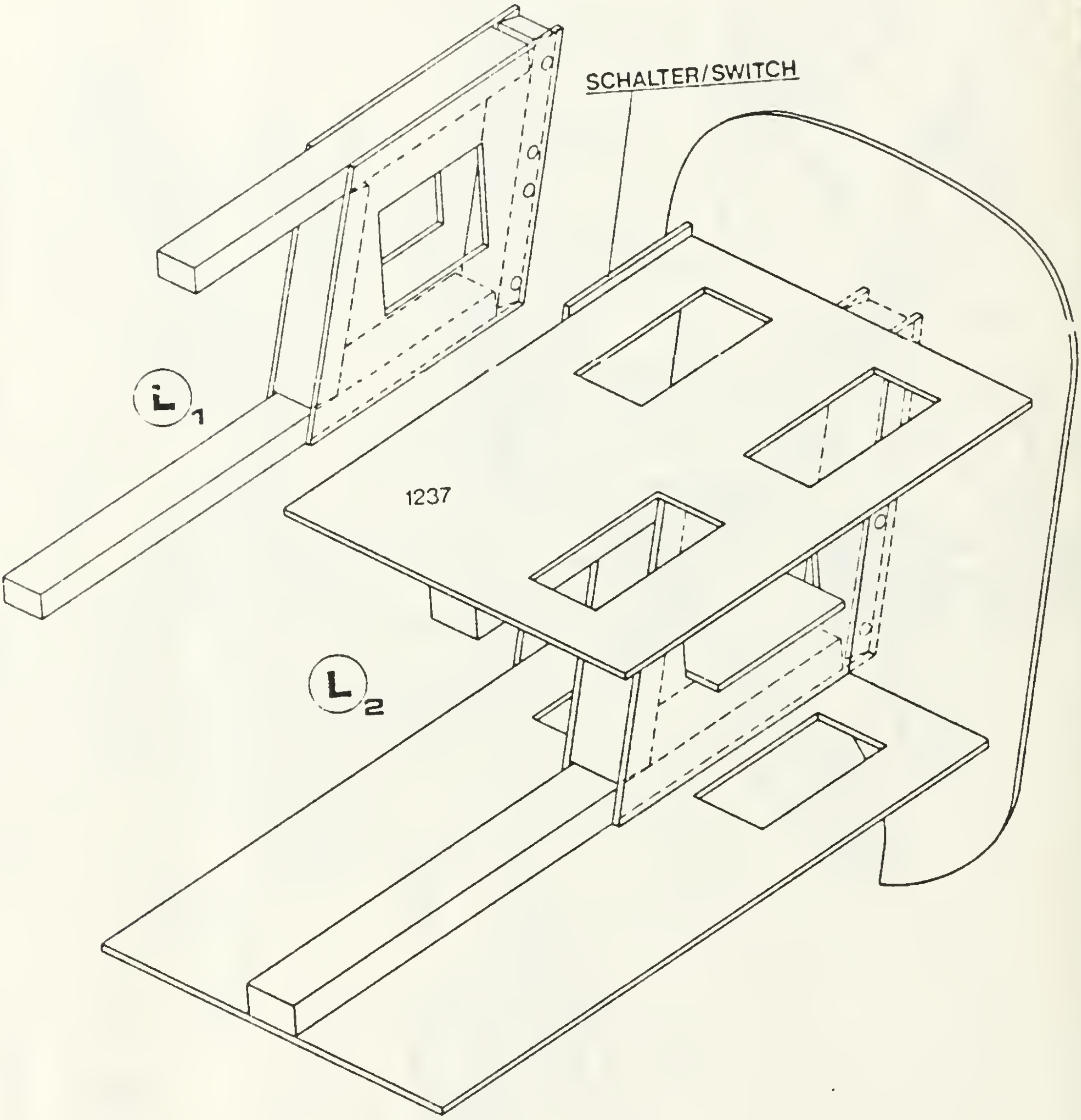

Figure A.8 Wooden Support Frame Assembly

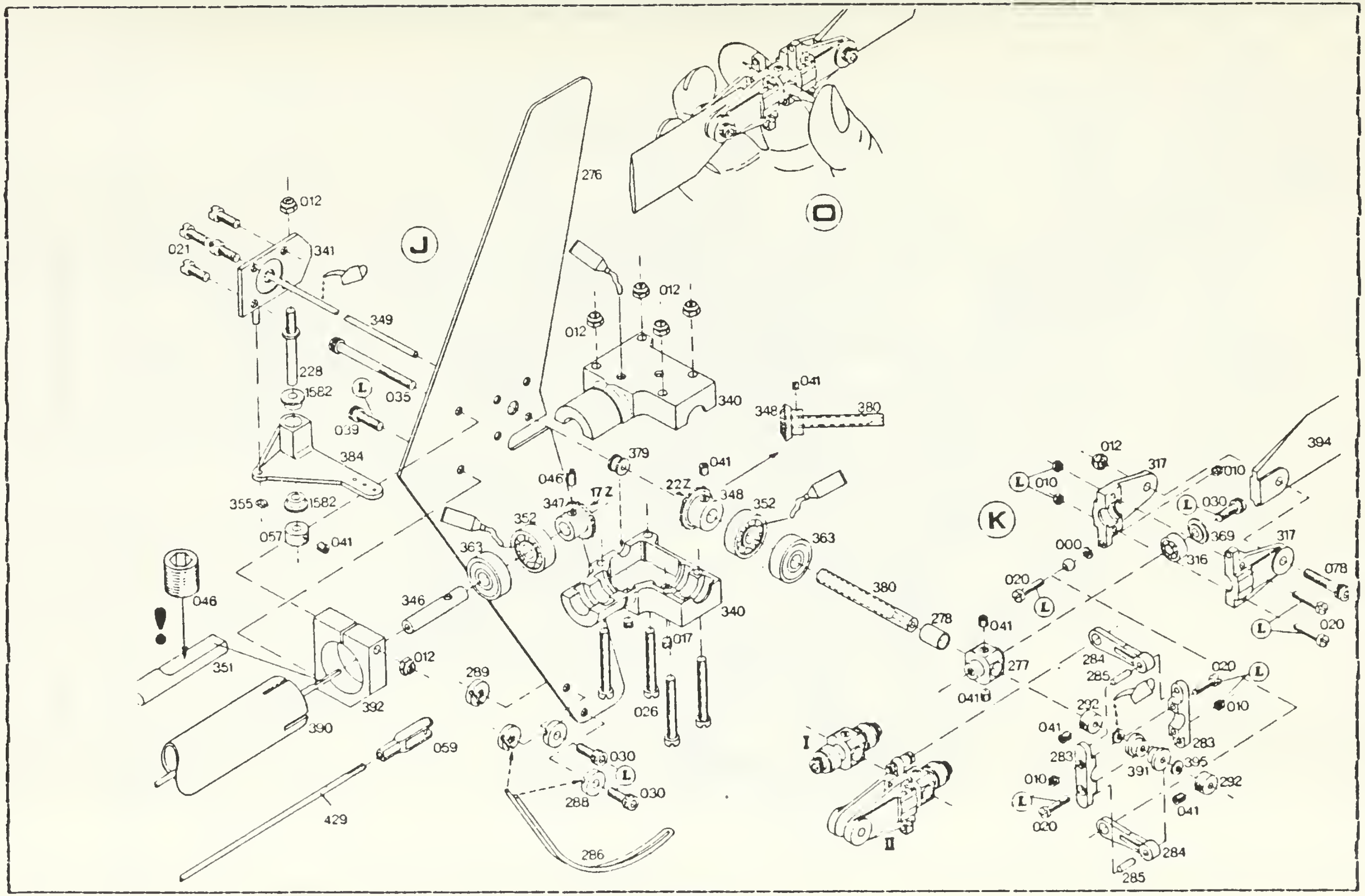

Figure A.9 Tail Rotor Assembly

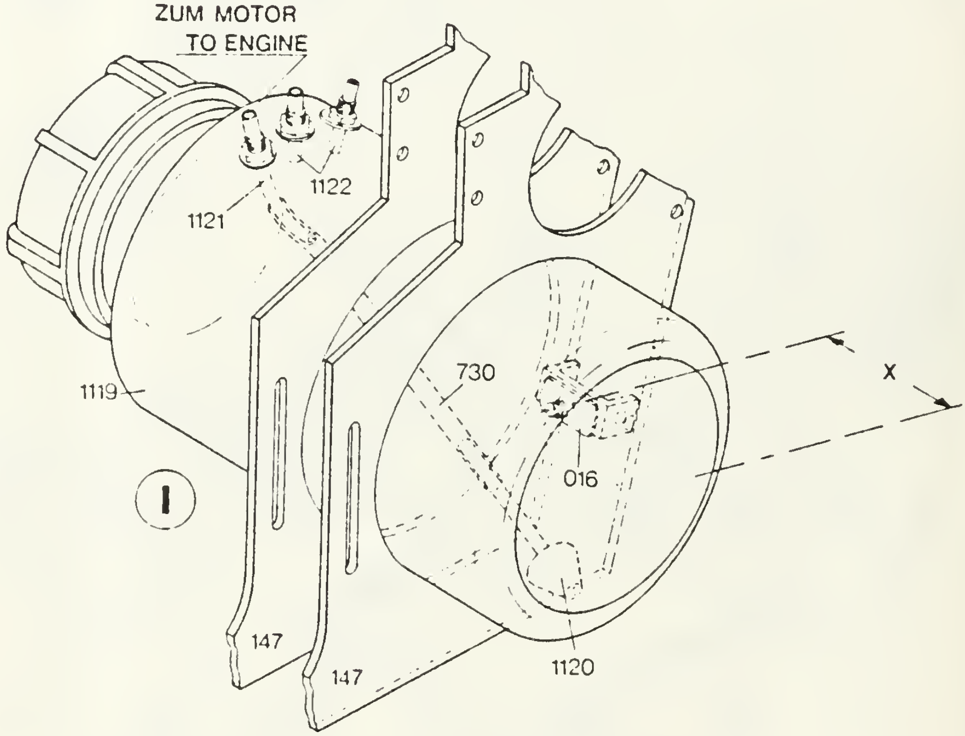

Figure A.10 Fuel Tank Assembly

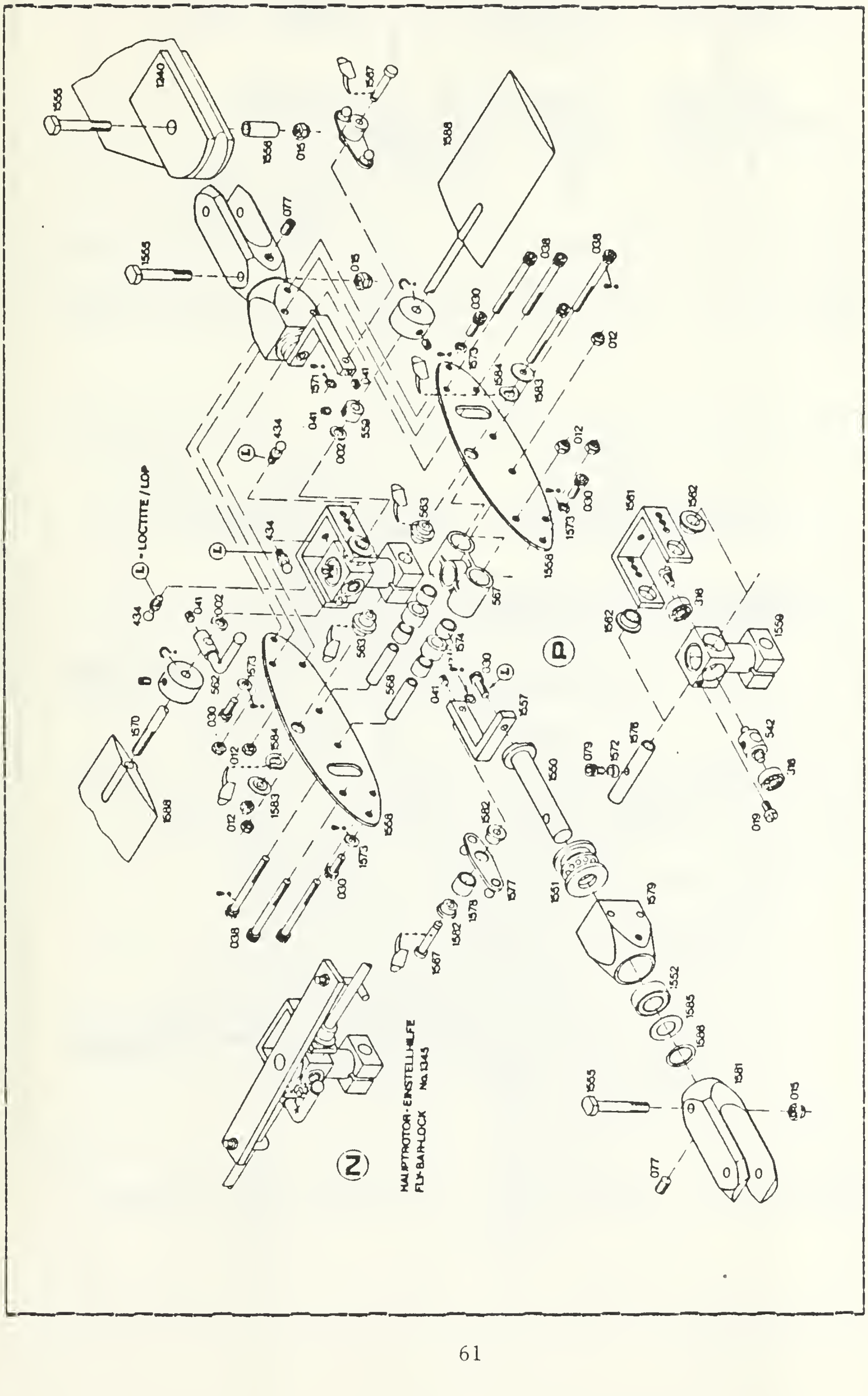

Figure A.11 Main Rotor Assembly

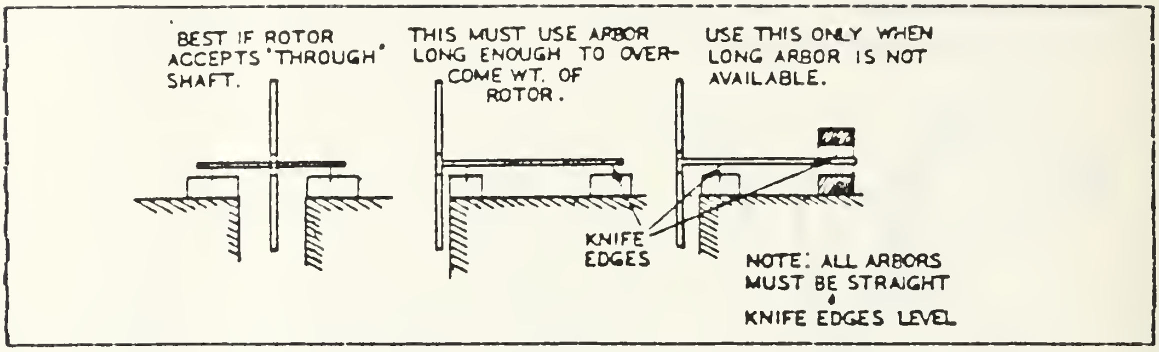

Figure A.12 Three Ways of Balancing the Main Rotor

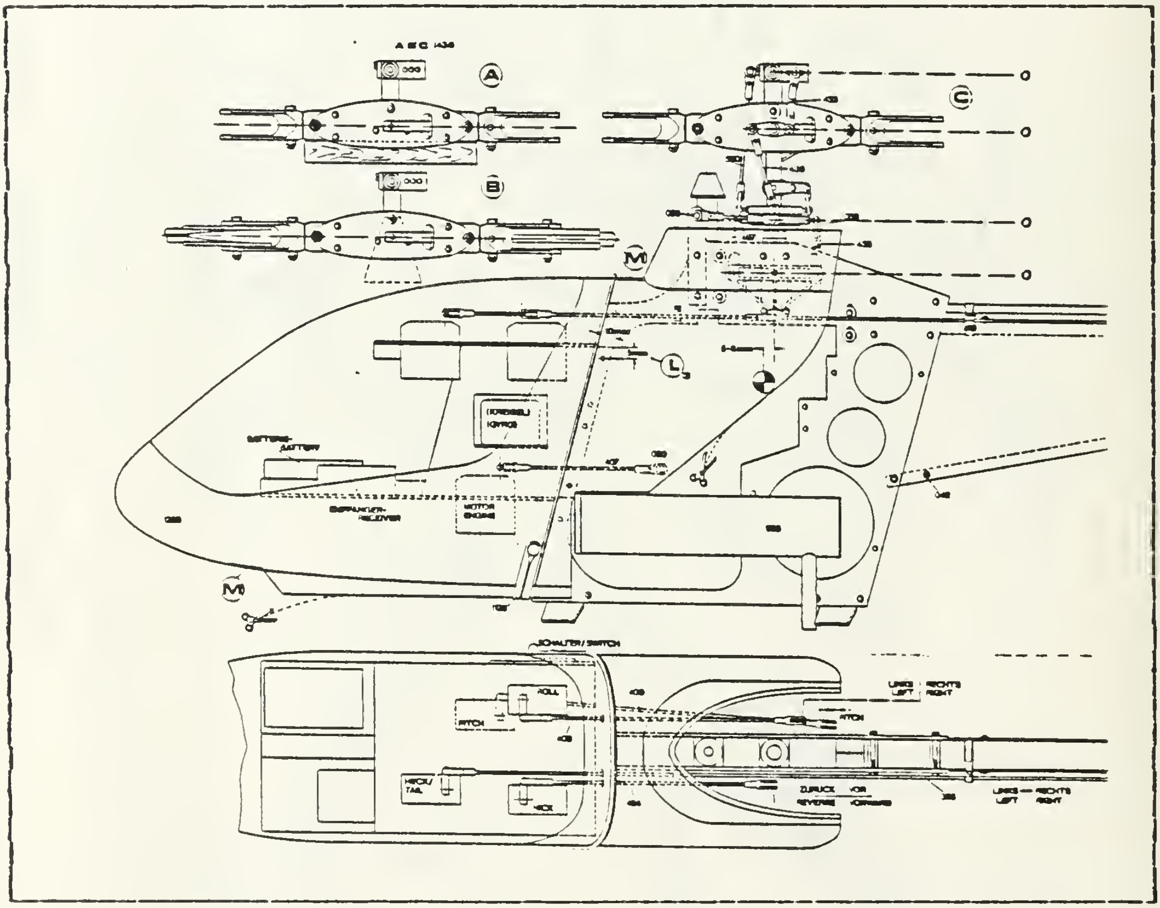

Figure A.13 Canopy, Servo & Control Rod Assembly

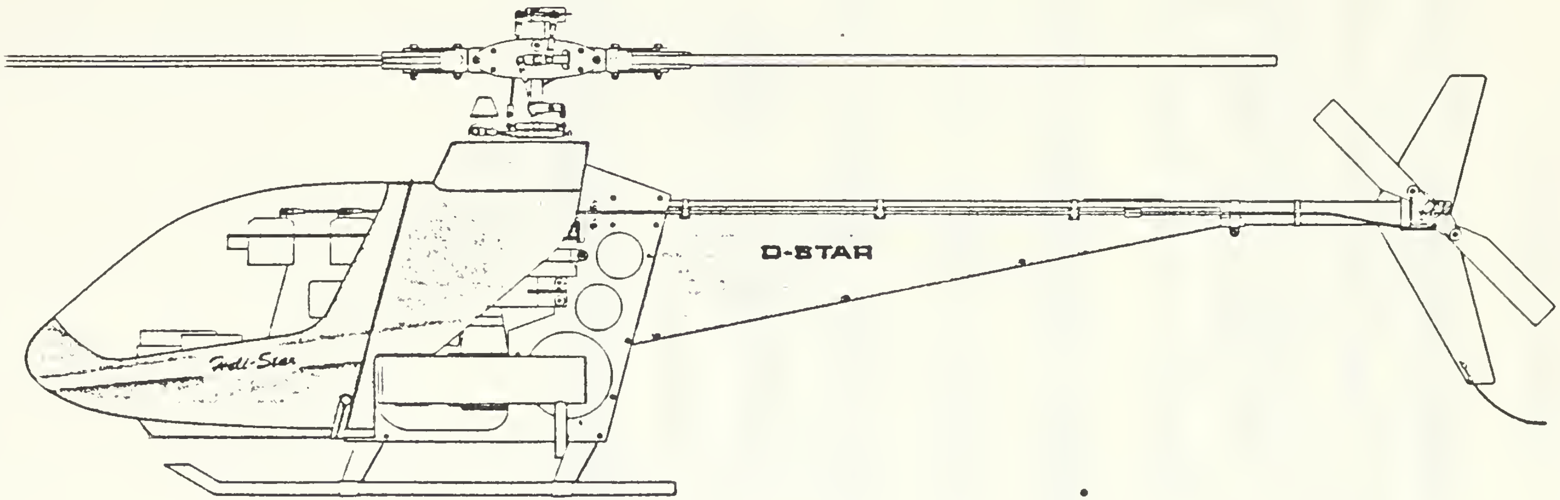

Figure A.14 Assembled Heli-Star Model Helicopter

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